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AN

Inaugural Dissertation

ON

ANIMAL HEAT.

BY PARDON BROWNELL.

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1814.

AN

INAUGURAL DISSERTATION

ON

Animal Heat;

SUBMITTED

TO THE PUBLIC EXAMINATION

OF THE

PRESIDENT AND PROFESSORS

OF THE

Medical Institution of the State of New-York,

AND THE

TRUSTEES OF QUEEN'S COLLEGE,

In the State of New-Jersey,

FOR THE

DEGREE OF DOCTOR OF MEDICINE,

On the 12th day of April, 1814.

TO THE

PRESIDENT AND PROFESSORS

OF THE

Medical Institution of the State of New-York,

THIS DISSERTATION

ON

ANIMAL HEAT,

IS

With a high sense of their liberality, and disinterested exertions for the promotion of Medical Science, and of the Author's obligations for their instruction and friendship,

MOST RESPECTFULLY

DEDICATED.

TO

DR. WILLIAM WHITRIDGE,

AND

DR. WILLIAM C. WHITRIDGE;

THIS

Dissertation is Inscribed,

AS

A Testimony of Respect,

AND AS

AN ACKNOWLEDGEMENT FOR THEIR INSTRUCTION,

BY

THEIR PUPIL,

THE AUTHOR.

DISSERTATION

ON

ANIMAL HEAT.

The general scholar and the disciple of medical science, are equally interested in the investigation of the phenomena of nature. No less magnificent and sublime in her great operations, than interesting and instructive in her minute details; she draws the attention of the former to the general laws of the universe, while the latter is attracted to her minuter operations and traces her course through the humblest functions of organized beings. In the economy of organized matter, the physiology of animals presents the most striking phenomena; and in this department of nature, perhaps there is nothing more difficult or more interesting, than the explanation of the nature and the causes of *Animal Heat*. The discussion of this subject will constitute the present essay.

In a matter of such difficulty, it would be presumptuous for the writer to maintain any original hypothesis. What he aims at, is to state some of the most authoritative theories on the subject, and to give a brief review of the arguments by which they are supported. This perhaps may be the best way of arriving at a doctrine which shall be more consistent in its parts, and more conformable to truth than most of the theories extant.

By Animal Heat is to be understood the excess of temperature which certain animals possess above that of the surrounding medium.

This excess of temperature is different in different animals. Zoologists have, therefore, divided them into two

classes. Those whose temperature is equal to, or higher than that of man are called warm-blooded—Those whose temperature is considerably lower, and who nevertheless are by their vis vitæ, kept somewhat warmer than the surrounding medium, are called cold-blooded animals. To this last class are referred the whole insect tribe, together with snails, frogs, toads, vipers and the serpent kind, as also the bronchial fishes and all testaceous animals. Man, by this division, holds the lowest grade in the warm-blooded class. The heat of the human body, in its natural state, has been variously estimated. Boerhaave and Pitcairn computed it at about 92° or 94° of Farenheit. M. Amontons estimated it at 93°. Sir Isaac Newton at 95 5°. Dr. Martine, Dr. Hales and Mr. Hunter, state it at 97° or 98°; and this we may conclude to be about the natural temperature of the human body in a healthy state. The temperature of ordinary quadrupeds, as oxen, sheep, dogs, swine, &c. is found by experiment, to be about four or five degrees above that of the human species. The temperature of cetaceous fishes, is about the same as that of quadrupeds. The bird kind are warmer by three or four degrees than quadrupeds; and Dr. Martine found the heat of a hen hatching eggs, to be as high as 108°. The following general observations on this subject, have been collected by Dr. Crawford.*

1. Those animals which are furnished with lungs, and which continually respire fresh air in great quantities, have the power of keeping themselves at a temperature considerably higher than the surrounding atmosphere: but animals that are not furnished with respiratory organs, are very nearly of the same temperature with the medium in which they live.

2. Among the hot-blooded animals, those are the warmest which have the largest respiratory organs, and which consequently breathe the greatest quantity of air in proportion to their bulk.

3. In the same animal the degree of heat is in some measure proportionable to the quantity of air inspired in a given

* See Crawford on Animal Heat, 2d Edit.

time; thus animal heat is increased by exercise, and whatever accelerates respiration.

It is to be further observed, that the degree of animal heat varies in different individuals, and even in the same animal at different times. In the healthful state, indeed, these variations are not great, yet by accidents or diseases they ascend considerably above, or descend considerably below the medium standard. Dr. Hales supposes the temperature of the human blood, in high fevers, to be about 136½°, but according to later and more accurate observations it is hardly ever found to exceed 112°.

After this brief statement of the phenomena of animal heat, it remains to consider the causes by which the phenomena are produced.

From the general observations of Crawford, above recited, there appears to be an intimate connexion between the function of respiration and animal temperature; and the physiologists of the present day are, I believe, generally agreed that the phenomenon of animal heat, is remotely or proximately occasioned by the mutual chemical changes effected on the air and on the blood in the act of respiration. The views which the science of chemistry has opened on this subject, affords one of the most striking instances of its application to physiology, and may be ranked among the most perfect elucidations which we are able to give of any function of the living system.

In the investigation of the causes of animal heat, it has now become necessary to devote particular attention to the circumstances which occur in the circulation of the blood, and in the function of respiration.

Before the modern discoveries in pneumatic chemistry, the most philosophical physicians entertained very crude notions concerning the effects produced on the blood in its circulation, and from its connexion with the respiratory functions. Baglivi supposed that the blood was rarified,* and Helvetious that it was condensed in its passage through the

* Opera, p. 457.

lungs.* Boerhaave imagined that the particles acquired that peculiar organization, which he thought essential to the existence of perfect blood.† Hervey, Boyle, Hales and Haller, thought that it parted with some noxious or superfluous matter, and with a quantity of aqueous vapour in the act of respiration.

Another class of physiologists conjectured that the air imparted something to the blood, which constituted its vital properties, and occasioned the difference between venous and arterial blood.

Boyle perceived that the air in passing through the lungs became loaden with vapour, and he farther supposed that it acquired what he calls recrementitious steams.‡ Mayow supposed that a peculiar volatile spirit was absorbed from the air during the passage of the blood through the lungs. Borelli and Willis seem to have entertained similar opinions.

For the first just ideas on this subject we are indebted to the learned Dr. Black, the father of pneumatic chemistry. In his experiments to ascertain the nature and properties of carbonic acid, he was led to observe that a portion of this gas, was exhaled from the lungs in the act of respiration.§— About this time the composition of the atmosphere was ascertained by the ingenious investigation of Scheele, Lavoisier and Priestley, and the agencies of oxygen, one of its principles, began to be observed with attention. Priestley considered respiration as analogous to what he called phlogistic processes in general, that is, to processes in which oxygen is consumed.¶ Lavoisier ascertained that the oxygen of the inspired air is partly consumed, and that in the process, carbonic acid gas is formed.‖‖

Various experiments have been institnted in order to ascertain the quantities of oxygen gas consumed, and of carbonic acid gas evolved in respiration during a given time. The results of these experiments have been extremely discordant,

* Mem. Acad. 1718.——† Prelect. t. ii, p. 184.——‡ Boyle's works, vol. i, p. 99 and seq. vol. iii, p. 371 and seq.——§ Statical Essays.—— ¶ Priestley's Exp. on Air, vol. iii, p, 362, 374—Phil. Trans. 1776.—— ‖‖ Mem. Acad. 1777.

owing to the inaccurate manner of conducting them, and to peculiar sources of fallacy which it is very difficult wholly to obviate.

Dr. Crawford, whose experiments deserve particular attention, as they were undertaken to illustrate the doctrine which is the subject of this essay, computed that while 40.86 cubic inches of carbonic acid gas were formed, 56.86 cubic inches of oxygen were consumed*. Dr. Goodwyn supposed that for 11 cubic inches of carbonic acid formed, there were consumed 13 cubic inches of oxygen gas.† The different experiments of Lavoisier and Seguin, are so discordant, that it would be useless to mention their results in this place. Mr. Davy states a consumption of 31.6 cubic inches of oxygen, during the formation of 26.6 cubic inches of carbonic acid gas.‡

By attending to the experiments of these philosophers, it would be found that they are all of them more or less liable to error, from the manner in which they were conducted; and the most general source of error might be traced to the difficulty of bringing the lungs to precisely the same state, at the close as at the beginning of the experiment.—Messrs. Allen and Pepys have more lately performed a course of experiments on this subject, which do not seem liable to the same objection. From the minuteness with which they are detailed, and the precautions with which they were executed, I am inclined to believe their result approaches as near the truth as it is possible to arrive, in a matter of such delicacy; and I am the more confirmed in this opinion by the testimony and explanations of a literary gentleman of my acquaintance, who was present and assisted in conducting many of the experiments. The result of them, so far as relates to the subject of this essay, may be summed up as follows:

1. They found that, in the formation of carbonic acid by the combustion of charcoal with oxygen gas, there is no change of volume; the volume the carbonic acid occupies, being exactly that which the oxygen gas filled.

* Crawford on Animal Heat.——† Goodwyn's Essay on the connexion of life with respiration.——‡ Researches, p. 431, 4.

2. The quantity of carbonic acid gas emitted from the lungs in respiration, is exactly equal, bulk for bulk, to the oxygen consumed.

3. Atmospheric air once entering the lungs, returns charged with from 8 to 8.5 per cent. of carbonic acid gas. Rapidity of respiration does not increase the proportion, although it augments the absolute quantity of carbonic acid in a given time.

4. A middle sized man gave off from his lungs in 11 minutes, 302 cubic inches of this gas. Taking this for a ratio, the total quantity for twenty-four hours would be 39,534 cubic inches; equal to rather more than 12 oz. Troy. A single inspiration (where about 19 respirations were made in a minute) was from 16 to 17 cubic inches.*

It may be proper here briefly to remark that in respiration, there is always a considerable portion of aqueous vapour contained in the air exhaled from the lungs. The quantity has been variously estimated. Dr. Hales computed it as high as 20 oz. in the twenty-four hours.† The nature of the process by which he computed it, did not admit of much accuracy; and it was doubtless greatly overrated in his estimate. Dr. Menzies supposes it to amount to no more than 6 oz. in twenty-four hours.‡ And Mr. Abernethy estimates the quantity exhaled in that time at about 9 oz.‖

It remains now to consider the changes effected in the blood during its circulation. Particularly the effects produced in its passage through the lungs, and its transition from the venous to the arterial state. If these changes can be clearly pointed out, we shall arrive at the principal sources of Animal Heat, by a natural and easy induction.

Soon after the discovery of the circulation of the blood, the distinction between its venous and arterial state was clearly pointed out, and the change was proved to be produced in the capillaries of the lungs. A great many conjectures were advanced to explain the nature of this change. The older

* Philosophical Transactions, 1808.——† Statical Essays, vol. ii, p. 322.——‡ Menzies on Respiration, p. 54.——‖ Essays, p. 54.

physiologists, as appears by the opinions of Baglivi, Boerhaave, Hales, Boyle and Haller, already quoted, endeavoured to account for it on mechanical principles. Doct. Priestley has the honor of being the first to open just views on this subject. He introduced a small quantity of venous blood into an inverted jar of atmospheric air. In a short time it assumed the arterial colour, and the air was found to have undergone the same changes in its chemical properties as by respiration.* The train of experiments so successfully opened by Priestley was pursued with avidity by Lavoisier, Dr. Crawford, and a number of distinguished physiologists. Their investigations resulted in two hypotheses considerably different from each other.

That during the passage of the venous blood through the lungs carbonic acid was exhaled, was doubted by none. But it was still doubtful in what manner it was formed. Either the oxygen of the atmosphere may combine directly with the carbon from the blood, and thus form the carbonic acid, or oxygen may be absorbed by the blood, and ready formed carbonic acid be discharged from it. The latter of these hypotheses was suggested by Lavoisier,† and subsequently supported by Hassenfratzs and Le Grange.‡ The former was maintained with ability by Crawford.§ Pursuing the ideas of Priestley, he at first called the inflamable matter thrown off in the lungs, Phlogiston, and afterwards, Hydrogen. But when the nature of hydrogen and carbonic acid became better known, he altered the term to Hydro-Carbon—the carburetted hydrogen of the modern nomenclature. He also rendered the hypothesis more comprehensive by assuming that the hydro-carbon was communicated to the blood in the extreme vessels, by which means the conversion from the arterial to the venous state was effected. In the lungs he concluded it to be given out by combining with oxygen and forming carbonic acid and watery vapour, while the blood

* Priestley's Exper. on Air. vol. iii, p. 358–360.——† Memoires d l'Acad. des Sciences, 1777, p. 191.——‡ Ann. de chim. t. ix, p. 261.——§ Observations on Animal Heat.

thus deprived of its hydro-carbon returned to the arterial state.

Hassenfratzs and Le Grange had observed that venous blood exposed to oxygen gas, soon acquired the vivid red colour of that of the arteries, and that arterial blood in contact with carbonic acid acquired the dark venous hue. From these observations they concluded that the blood absorbed oxygen in the lungs, which remained for a time in a state of solution or loose combination, but gradually passed in the extreme vessels into a state of more intimate combination with carbon, producing the change from the arterial to the venous state, and forming the carbonic acid which is given out in respiration; while a new portion of oxygen was absorbed in the passage through the respiratory organs, and the blood again changed to the arterial state.

Neither of these hypotheses are free from objections. It may be remarked upon them generally, that neither of them will explain all the phenomena connected with them, that their leading principles remain to be proved, and that they involve principles not consistent with general laws that regard other chemical actions of the animal system. Some of the objections against Crawford's theory have been well urged by Dr. Bostock,* and both hypotheses are controverted by Mr. Murray.†

With respect to the theory of Crawford, there is no reason to believe that hydro-carbon is communicated to the blood in the extreme vessels in an insulated state. And though he assumes it to be derived from the solid parts of the system, which are acknowledged to be continually changing, yet it should be observed that this absorption is performed not by the veins, but by the lymphatic vessels. Such a source of inflamable matter would hardly be sufficiently uniform to account for the uniform change of the blood; neither is it reasonable to suppose that the matter derived from the decay of the system would be confined to carbon and hydrogen. Add to this, that there is good reason to believe that

* Essay on Respiration, p. 112.——†System of Chemistry, vol. iv, p. 541.

no union of oxygen and hydrogen is effected in the lungs, but that the halitus or pulmonary exahalation is produced by evaporation from the mucous fluid which lubricates the inner surface of the bronchia and vesicles, and which is separated from the blood by secretion. This opinion is warranted by the experiments of ALLEN and PEPYS, before referred to, as well as by considerations which might be adduced from the necessity of such an evaporation to moderate the temperature of the lungs.

As to the theory of HASSENFRATZS, it remains to be proved that any absorption of oxygen takes place in the lungs, or that such absorption occasions the florid hue of arterial blood. From the capital experiment of PRIESTLEY, it would be rather inferred that this change of colour was produced, not by the absorption of oxygen, but by the disengagement of inflamable matter from the venous blood. I know not whether any direct proofs of either of these suppositions have been adduced; but I am rather surprised if there have not, in a matter of so easy demonstration. I have instituted two or three experiments to ascertain the fact; and from their result I have additional reason to incline to the inference that would be deduced from PRIESTLEY's experiment. Blood was drawn from the jugular vein of a bullock into glass tubes, which were immediately hermetically sealed with a quantity of atmospheric air in them, about equal in bulk to the blood. After standing some time, being agitated occasionally, the blood assumed the vivid red arterial hue. A tube was then opened under water, and as no absorption took place, it might be concluded that no diminution had taken place in the air. The air was then analysed; first by agitation with lime-water to abstract the carbonic acid, and then with a solution of sulphate of iron, saturated with nitrous gas to absorb the remaining oxygen. The result was that a sufficient quantity of oxygen could be accounted for, to amount to 21 per cent. of the air contained in the tube, and of course no oxygen remained in the blood as HASSENFRATZS supposed; either in a state of solution, or of loose combination as he paradoxically termed it.

But were it to be admitted that oxygen is absorbed by arterial blood, it has not been proved that it combines with carbon merely. Much less can it be proved that carbonic acid, in solution or mixture, constitutes the difference between venous and arterial blood. Indeed the contrary of this may be fairly inferred from an experiment of PRIESTLEY. When arterial blood was exposed to carbonic acid till its colour became darkened, it did not recover its florid hue from subsequent exposure to oxygen, and therefore was not in the venous state.

A very just view of the changes which the blood undergoes in the course of its circulation has been given by Mr. MURRAY.

"The blood," says he, "is the source whence all the parts "of the body and the products of the system are formed. Its "expenditure is constantly supplied by the chyle, a fluid "less completely animalised than the blood itself. The pe- "culiar character of animal matter, with regard to composi- "tion, is a large proportion of nitrogen, and a diminished pro- "portion of carbon. It may, therefore, be inferred that in "the extreme vessels, when the animal solids and fluids are "formed, the general process will be the separation from the "blood of those elements of which animal matter is compos- "ed; and that of course, carbon, which enters more sparing- "ly into its composition, will exist in the remaining blood in "an increased proportion. This is accordingly the general "nature of *the conversion of arterial into venous blood.* Ni- "trogen, hydrogen, and other elements, are spent in the for- "mation of new products, and the proximate principles of the "blood, probably the crassamentum chiefly, remain with an "increased proportion of carbon. In this state it is exposed, "under a very extensive surface, to the atmospheric air in the "lungs, the oxygen of which abstracts its excess of carbon, "and forms the carbonic acid expired, and this constitutes "*the conversion of venous into arterial blood.*"

System of Chemistry, v. iv, p. 543.

This view of the circumstances which take place during respiration and the circulation of the blood, illustrates very happily the final causes of those processes, and accords well

with the other chemical changes which take place in the system.

After this discussion upon the changes that take place in the air and in the blood; before we can fairly arrive at the sources of animal heat, and the principles which regulate its distribution, it remains to advert to one or two chemical facts relating to heat.

Dr. Black has the honour of being the first who pointed out distinctly the principles of specific and latent heat. The field which he opened was explored with much zeal by Irvine, Crawford, Lavoisier, and the most distinguished philosophers of the age.

The fundamental doctrine of specific heat is, that equal quantities of different bodies at the same temperature, contain unequal quantities of caloric, or in the technical language, that some bodies have a greater *capacity* for caloric than others.

The fundamental doctrine of *latent* heat is, that bodies in passing from a solid to a liquid or from a liquid to an aeriform state, absorb caloric without increasing their temperature; and conversely, that bodies in passing from an aeriform to a liquid, or from a liquid to a solid state, give out caloric without a diminution of temperature. And more generally, that bodies in passing from a denser to a rarer state absorb heat, and in passing from a rarer to a denser state give out heat, without affecting the temperature of the bodies themselves. The heat thus absorbed or extricated is called *latent heat.*

It was upon these principles, and from an observation of the changes which take place in the air and in the blood, during respiration and the process of circulation that Dr. Crawford built his theory of Animal Heat.

It had not indeed escaped the sagacity of Dr. Black, that the source of animal heat might be traced to respiration. And he had accordingly advanced such an opinion, founded on his observation of the analogy between respiration and combustion, with respect to the change which the air undergoes; and upon the observation that the temperature of different animals is nearly in proportion to the size of their lungs and the quantity of air they consume; but to Dr. Crawford is

due the honour of the theory, and of its elucidation by the most extensive and minute investigation.

From the chemical actions which take place in respiration, Dr. CRAWFORD has proved that a great quantity of caloric must be evolved in the lungs. Oxygen combines with carbon and forms carbonic acid. But the capacity of carbonic acid is much inferior to the mean between the capacities of oxygen and carbon. Caloric must therefore be extricated. A little detail will illustrate this fact.

The capacity of oxygen gas is stated at 4.749; the capacity of carbon at 0.263, or equal weights of carbon and oxygen gas at the same temperature, contain quantities of caloric in this ratio. The capacity of the carbonic acid, formed by their combination, is 1.045, much inferior to the mean between the oxygen gas and the carbon. A great quantity of caloric must therefore be given out from the oxygen gas durin this change of its capacity. But during this process about 72 parts of oxygen combines with 28 parts of carbon. Taking this circumstance into consideration, it can be shown, as Dr. CRAWFORD has done, that from the diminution of capacity attending the combination of oxygen and carbon, as much caloric must be extricated as, if not otherwise disposed of, but applied to the carbonic acid, would raise its temperature more than four times the excess of the heat of red hot iron, above the common temperature of the atmosphere.*

Dr. CRAWFORD further proved by experiments, that the capacity of the blood changes in its passage from the arterial to the venous, and of course from the venous to the arterial state. The relative capacity of the arterial to that of the venous blood, he found to be as 1.030 to 0.892; consequently, during the conversion of venous blood to the arterial state, caloric must be absorbed; and, during the conversion of arterial into venous blood, caloric must be extricated.

Upon the principles and facts here stated, is founded the doctrine of *Animal Heat;* its principal source, and the manner of its distribution through the system.

* Crawford on Heat, p. 402.

This doctrine may be summarily stated in a few simple propositions; and the preliminary discussion we have gone through, will, I think, serve to render it easily intelligible.

1. The air inspired contains more absolute heat than the air expired; consequently in the process of respiration a quantity of heat must be evolved in the lungs.

2. The blood is changed at this moment from the venous to the arterial state, and acquires an increased capacity for caloric. It therefore takes up the heat which has been evolved in the lungs; so that any rise of temperature which would be distructive to life, is prevented.

3. The arterial blood circulates through the body, and in the extreme vessels passes into the venous state. During this conversion, its capacity is diminished, as much as it had been enlarged in the lungs; the caloric which it took up there is here given out; and this slow and constant evolution of heat, in the extreme vessels over the whole body, is the source of its uniform temperature.

Thus oxygen gas, by its passing from a rare into a denser state, in respiration, and consequently changing its capacity for caloric, is the primary source of Animal Heat. The circulation of the blood, and its alternate increase and dimunition of capacity in its changes from the venous to the arterial, and from the arterial to the venous state, is the channel of its distribution and equable diffusion through the system.

The peculiar characteristic, and the greatest excellency of Dr. Crawford's theory of Animal Heat, is derived from the views he has given of the changes of capacity the blood undergoes; and though we have had occasion to doubt the correctness of his opinions as to the source of the inflamable matter ejected in the lungs, and as to the fact of any hydrogen being evolved there, yet as the principles of the theory are independent of any particular hypothesis respecting respiration, and as they seem so fairly established by known chemical laws, we do not hesitate to yield to it, in the main, our most ready assent, and to testify our highest respect for its indefatigable and ingenious author.

The direct experiment by which Dr. Crawford supposed that he had established the correctness of his doctrine was afterwards repeated by Lavoisier and La Place, with the same result. An animal was enclosed in a vessel so constructed as exactly to measure the quantity of air consumed; and the quantity of caloric evolved in a given time. The quantity of caloric was found to correspond with the quantity that would be evolved in the combination of the same quantity of oxygen, with any carbonaceous matter in ordinary combustion.*

It is a little extraordinary that the acute Mr. John Bell, in remarking on the theory of Dr. Crawfod, should have hazarded the assertion, that "his doctrines begin not with a a fact, but with a *petitio principii*, and what is worse, his main experiment is wrong.† Surely if this author's fondness for smart criticism, and his contempt for established principles, had not prevailed over his better judgment, he could not have failed to perceive that this theory, instead of being founded on a *petitio principii*, or any other sophism, was one of the completest inductions from facts and chemical principles, of any doctrine in animal physiology.

The main experiment of Crawford, which Mr. Bell so promptly pronounces wrong, is the experiment stated just above, and which, if it be erroneous, throws an equal share of the imputation of want of sagacity, on Lavoisier and La Place.

"Dr. Crawford," says Mr. Bell, "was extremely anxious to prove that in proportion as air was changed in respiration, it gave out heat to the blood; he also wished to put respiration and combustion on one level; and by this second thought, he forgot entirely what he first had in mind to prove. Accordingly his experiment proves more than he had intended; for he proved plainly by it, that all the heat which respiration can possibly generate, is by means of the carbonic acid carried from the lungs, and he forgot to reserve any for going into the blood."

* Crawford on Animal Heat.

† Anatomy of the Heart and Arteries.

Such flippancy of remark betrays a mind but little disposed to minute and candid observation. It is, therefore, not surprising that Mr. Bell has failed to perceive that the heat rendered sensible in this experiment, instead of being evolved directly from the lungs, might be absorbed by the blood and and afterwards extricated from the animal.

Mr. Bell has not thus peremptorily rejected Dr. Crawford's theory without proposing a substitute. According to his hypothesis, animal heat does not originate in the lungs, "but is produced by the action of vessels in each part of the body." And he concludes his doctrine by observing, "that oxygen, if it do communicate heat, does so, not to the lungs, nor to the blood, but to the whole body through the medium of the blood." He supposes that the blood unites with oxygen in its passage through the lungs, and that this oxydation, as he terms it, causes the difference between venous and arterial blood. "Oxydation," says he, "is a process which had no place in Dr. Crawford's views; he never conceived that it was the presence of oxygen, as a new principle, which gave colour, coagulability, stimulant powers and all its most useful properties to the blood."

Of this process of oxydation, however, Mr. Bell seems to have but very confused ideas. "It is not a perfect oxydation"—nor "a fair oxydation"—nor "a permanent oxydation." Indeed, according to him, it is no oxydation to all; for he says, that "the oxygen is not so much united with the blood, as conveyed by it, and perhaps it is only when this principle is taken from the blood, and assimilated with the several parts of the body and fixed among its solids, that it gives out heat at all."*

Mr. Bell's theory might pass without notice, were it not that his ideas, confused as they are, do not seem to differ much from those of Hassenfratzs and Le Grange and their followers. The "imperfect oxydation," spoken of by the former, seems much of a piece with the "solution, or loose combination" of the latter; and all of them appear to agree that there can be no extrication of caloric in the lungs.

* Anatomy of the Heart and Arteries, p. 47.

It may not be amiss here to offer a few remarks in addition to what has been already said on this subject.

With respect to this "imperfect, or loose combination," it may be observed, that if there be no affinity between oxygen and the blood, there can be no combination at all, and consequently no absorption. Again, no combination or absorption can take place, unless this affinity be sufficiently powerful to overcome the attraction between the oxygen and nitrogen of the atmosphere. And further, the affinity must be sufficiently strong to overcome this attraction not only, but it must be a very powerful affinity, or the combination could never take place through the membrane of the lungs.

With respect to the extrication of caloric in the lungs, the advocates of the hypothesis, which is here combatted, are placed in a very difficult dilemma. Either oxygen gas in its totality must be absorbed, or caloric must be evolved in the lungs.

The first of these alternatives will hardly be embraced, when the consequences of its admission are well understood. In respiration, about 3 or 3.5 per cent. of the oxygen of the atmosphere is consumed. A common man inhales about 16 or 17 cubic inches of air at one inspiration; and, in health, makes 19 or 20 inspirations in a minute.* Upon these data a volume of about 25 cubic inches of air must be thrown into the arteries every minute. I know not that any uncombined oxygen gas is contained in the arterial blood, but upon this hypothesis its volume must be much greater than that of the arterial blood itself.

If Mr. Bell chooses to combat us on the other horn of the dilemma, he will scarcely find his theory more tenable. Mr. Bell must be chemist enough to be aware of the distinction between oxygen and oxygen gas. And though in common language we use these as convertable terms, yet when we speak of the combination of oxygen, we must keep in mind the difference between its separate state and combination with caloric, constituting its gaseous state. Now if it be admitted that oxygen gas, in its totality, cannot be absorbed by

*Allen and Pepys on Respiration—See Nicholson's Journal, v. xxii, p. 180.

the blood, then, if any absorption takes place, it must be of the oxygen in its seperate state; and of course the caloric which it held in combination must be extricated. Oxygen gas is the great repository of caloric in nature, and the new combinations of oxygen are the great sources of sensible heat. It has been shown, I think, that if any oxygen be absorbed in the lungs, it must enter into an intimate combination with the blood, in consequence of a strong affinity; and it is a well known chemical law, that oxygen never enters into a new combination from its gaseous state without an evolution of caloric.

I do not know whether these arguments have ever been advanced by the advocates of CRAWFORD's theory; but to me they appear conclusive in its favour.

After having stated the general facts relating to animal heat, the principle source from which it is derived, and the manner in which it is distributed through the system, it remains to notice a few of the circumstances by which it is modified.

Violent exercise is found materially to raise the animal temperature; and, as might be expected, to increase the quantity of the air consumed in respiration. LAVOISIER and SEGUIN have shown that a man who ordinarily consumed about 1350 cubic inches of oxygen in an hour; by subjecting himself to severe exercise, consumed at the rate of more than 3000 cubic inches in the same time.* The same Philosophers found that the temperature of the body was increased during the process of digestion, and that under those circumstances the consumption of oxygen amounted to about 1800 or 1900 cubic inches in an hour.

Though we reject the theory which supposes all animal heat to be derived from the changes which the aliment undergoes, and from the process of animalization; we are free to admit that these processes have some effect in modifying the animal temperature. To calculate these effects would be impossible; and it is most probable that, in general, there are

* Memoires de l'Acad. des Sciences, 1789.

opposite processes which nearly counterbalance each other. These processes must all fall under the general law, that whenever any substance passes from a rarer to a denser state, heat will be given out, and whenever any substance passes from a denser to a rarer state, heat will be absorbed.

The influence of external temperature upon the heat of animals is much less than might have been inferred by reasoning *a priori*. The ancients could not believe the torrid zone to be habitable by the human species. Dr. Boerhaave related experiments from which it would appear that animal life was soon destroyed at a temperature of 146°, and he has supposed that the serum of the blood becomes coagulated at a temperature but little above that of its natural heat.* All fears, however, that the blood might coagulate in the vessels, by the animal heat, have been removed by subsequent experiments, and the fallacy of the experiments related by Boerhaave has been completely proved.

M. Tillet first found out by accident that, contrary to generally received opinions, it was possible for a person to breathe for several minutes, without injury, in an atmosphere heated to the temperature of 260°.†

Dr. George Fordyce, prepared a suit of rooms, heated by flues, and in conjunction with Sir Joseph Banks, Dr. Blagden and others of his friends, instituted an extensive course of experiments on this subject. These gentlemen exposed themselves several minutes in a room heated to the temperature of 212°. without inconvenience, and without the natural temperature of their bodies being perceptibly raised. Whenever they breathed on a thermometer, the mercury was observed to sink several degrees, and their breath afforded a pleasant, cooling sensation to their nostrils. Dr. Blagden, on touching his side, perceived it to feel like a corpse, although its actual temperature was 98°; at the same time his watch chain felt so hot he could scarcely bear its touch. In subsequent experiments, the rooms were heated as high as 260°. This excessive heat was borne for several minutes,

* Statical Essays.

† Hist. Acad. Sciences, 1764, mem. ii.

with but little inconvenience. The temperature of the body was scarcely raised, though the velocity of the pulse was more than doubled. In this air which they breathed, eggs were roasted quite hard in 20 minutes; beef-steaks were dressed in 33 minutes, and by blowing a stream of the air on them even in 13 minutes.*

Upon these experiments, and others of a similar nature, made by himself in the sweating rooms of the hospital at Liverpool, Dr. Dobson observes, that since the pulse is greatly accelerated, while the animal heat scarcely varies by an increased temperature, that theory of animal heat cannot be correct which attributes its production to the attrition of the globules of the circulating fluids against the sides of the containing vessels.†

To account in a satisfactory manner for the extraordinary phenomenon established by the foregoing experiments, would, probably, be a very difficult task. It must doubtless result in a great degree from the relative capacities between arterial and venous blood, at different temperatures, as its proximate cause. And this must in all probability be influenced by causes which modify the expenditure of certain principles in the extreme vessels. Dr. Crawford has proved, by experiments, that less oxygen is consumed by respiration, at a high than at a low temperature.‡ Lavoisier and Seguin, have also found that the same person who consumed 1344 cubic inches of oxygen gas in an hour, at the temperature of 54°, consumed only 1210 cubic inches at the temperature of 79°.§

Dr. Crawford also observed, that when an animal was exposed to a high temperature, the venous blood approached near to the arterial in its colour. From this he inferred that an elevated temperature counteracts those chemical changes which the blood undergoes in the extreme vessels, and that the diminution in consumption of oxygen is owing to this cause.

* Philosophical Transactions, vol. lxv.
† Philosophical Transaction, vol. lxviii.——‡ Experiments on Animal Heat, p. 307.——§ Memoires de l'Acad. des Sciences, 1789, p. 575.

It may be further remarked on this subject, that the temperature of animals in a high medium, is much moderated by evaporation from the lungs, and by perspiration from the external surface. Lavoisier and Seguin have estimated the quantity of vapour given off in twenty-four hours, from a person not under any bodily labour, at 15 ounces by halitus, and 30 ounces by cutaneous transpiration.* At a high temperature these functions are known to be greatly increased, and when it is considered that every pound of water, in vaporization, absorbs heat sufficient to raise 800 or 900 pounds one degree, their effects in moderating the animal temperature may be correctly appreciated.

A thorough knowledge of the doctrine of Animal Heat, and the causes which excite and modify it, would, doubtless, throw much light on the causes and nature of febrile and inflammatory diseases; but it does not fall within our design to point out this connexion. Such a knowledge would also give us much information concerning the effects of heat and cold on the human system. From what has just been detailed, it would appear that extremes of heat and cold, unless carried to a considerable extent, have but little effect on the animal temperature, and they seem to be rather the remote than the immediate causes of disease.

I conclude this essay by remarking the happy contrivances of nature to correct her own extremes. Man by his organization is so constituted as to retain the same temperature in all regions of the globe; and changes his clime to suit his pleasures or convenience. By similar contrivances the inferior animals are adapted to their different destinations.—The lizard remains cool under the burning sun of the equator, while the whale, in the polar seas, amidst mountains of ice, retains a degree of heat superior to that of the human body.

* Memoirs de l'Acad. des Sciences, 1790, p. 601.